



Digital F/T System

Installation and Operation Manual



Document #: 9620-05-Digital FT
August 2014

Engineered Products for Robotic Productivity

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Note

Please read the manual before calling customer service. Before calling, have the following information available:

1. Serial number (e.g., FT01234)
2. Transducer model (e.g., Nano17, Gamma, Theta, etc.)
3. Calibration (e.g., US-15-50, SI-65-6, etc.)
4. Accurate and complete description of the question or problem
5. Computer and software information. Operating system, PC type, drivers, application software, and other relevant information about your configuration.

If possible, be near the F/T system when calling.

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Glossary of Terms

Term	Definition
Calibration	The act of measuring a transducer's raw response to loads and creating data used in converting the response to forces and torques.
End-Effector	Any object attached to the robot flange (wrist) that serves a function. This would include robotic grippers, robotic tool changers, robotic crash protection, robotic rotary joint, robotic press tooling, compliance device, robotic paint gun, robotic deburring tool, robotic arc welding gun, robotic transgun, etc. End-effector is also known as robotic peripheral, robotic accessory, robot or robotic tool, end-of-arm (EOAT) tooling, or end-of-arm device.
F/T	Force/Torque.
F/T Transducer	Converts force and torque into an electrical signal.
Hysteresis	A source of measurement error caused by the residual effects of previously applied loads.
MAP	The Mounting Adapter plate (MAP) is the adapter plate that attaches to the fixed surface or robot arm.
Modbus	Modbus Protocol is a messaging structure used for master-slave/client-server communication between intelligent devices.
NI	National Instruments Corporation, the owner of the National Instruments and LabVIEW trademarks. (www.ni.com) Maker of Data Acquisition Cards used by ATI in force sensors.
Overload	The condition where more load is applied to the transducer than it can measure. This will result in saturation.
Saturation	The condition where the transducer or data acquisition hardware has a load or signal outside of its sensing range.
TAP	Tool Adapter plate (TAP) is the transducer surface that attaches to the load to be measured.
Tool Transformation	Mathematically changing the measurement coordinate system by translating the origin and/or rotating the axes.
Transducer	Transducer is the component that converts the sensed load into electrical signals.
UDINT	A data type representing an unsigned integer with 32 bits.
UINT	A data type representing an unsigned integer with 16 bits.
USINT	A data type representing an unsigned integer with 8 bits.

1. Safety

The safety section describes general safety guidelines to be followed with this product, explanation of the notification found in this manual, and safety precaution that apply to the product. More specific notification are imbedded within the sections of the manual where they apply.

1.1 Explanation of Notifications

The notifications included here are specific to the product(s) covered by this manual. It is expected that the user heed all notifications from the robot manufacturer and/or the manufacturers of other components used in the installation.



DANGER: Notification of information or instructions that if not followed will result in death or serious injury. The notification provides information about the nature of the hazardous situation, the consequences of not avoiding the hazard, and the method for avoiding the situation.



WARNING: Notification of information or instructions that if not followed could result in death or serious injury. The notification provides information about the nature of the hazardous situation, the consequences of not avoiding the hazard, and the method for avoiding the situation.



CAUTION: Notification of information or instructions that if not followed could result in moderate injury or will cause damage to equipment. The notification provides information about the nature of the hazardous situation, the consequences of not avoiding the hazard, and the method for avoiding the situation.

NOTICE: Notification of specific information or instructions about maintaining, operating, installation, or setup of the product that if not followed could result in damage to equipment. The notification can emphasize but is not limited to specific grease types, good operating practices, or maintenance tips.

1.2 General Safety Guidelines

The customer should verify that the transducer selected is rated for maximum loads and moments expected during operation. Refer to F/T Transducer Manual (9620-05-Transducer Section—Installation and Operation Manual) found in Net F/T Installation and Operation Manual (9610-05-1022) or contact ATI Industrial Automation for assistance. Particular attention should be paid to dynamic loads caused by robot acceleration and deceleration. These forces can be many times the value of static forces in high acceleration or deceleration situations.

1.3 Safety Precautions



CAUTION: Do not remove any fasteners or disassemble transducers without a removable mounting adapter plate. These include Nano, Mini, IP-rated, and some Omega transducers. This will cause irreparable damage to the transducer and void the warranty. Leave all fasteners in place and do not disassemble the transducer.



CAUTION: Do not probe any openings in the transducer. This will damage the instrumentation.



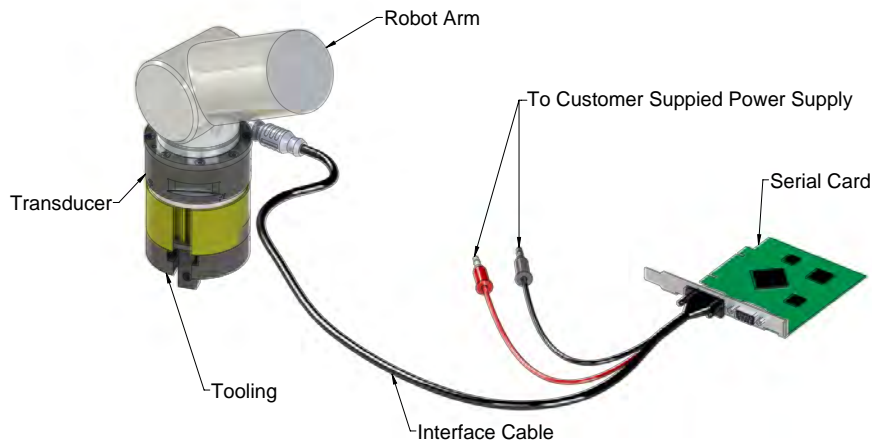
CAUTION: Do not exert excessive force on the transducer. The transducer is a sensitive instrument and can be damaged by applying force exceeding the single-axis overload values of the transducer and cause irreparable damage. Small Nano and Mini transducers can easily be overloaded during installation. Refer to the F/T Transducer manual (9620-05-Transducer Section) for specific transducer overload values.

2. Product Overview

The Digital F/T connects using a high-speed RS-485 interface cable. The transducer's six strain gage values are digitized and sent over the high-speed interface cable to the host computer through a Serial Card, where software provided by ATI or customer software calculates the F/T data.

NOTICE: The system requires a computer with a RS-485 interface capable of communicating at 1.25 megabits/second.

Figure 2.1—Product Overview



2.1 Serial Card

The Serial Card provides a RS-485 serial bus interface for ATI's RS-485 interface cable. The Serial Card interfaces with a user supplied computer. The serial card has to support a 1.25 MB baud rate.

2.2 Interface cable

A NET sensor to RS485 interface cable (9105-CF-MTS-DB9-X.X) is required to connect the transducer to the Serial Card and user power supply.

2.3 Power Supply

The Digital F/T system requires a customer supplied power supply with a voltage output of +12 VDC to +18 VDC and ability to supply 3 watts.

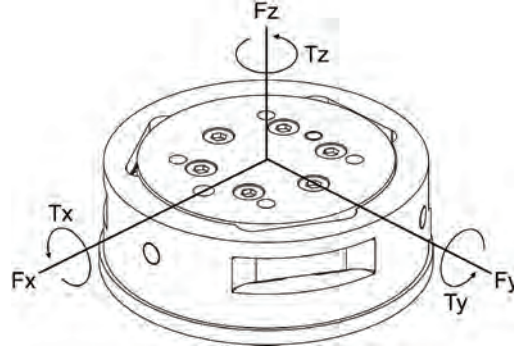
2.4 Transducers

The Digital F/T System connects directly to Net Transducers.

2.4.1 Transducer Functionality

The property of forces was first stated by Newton in his third law of motion: For every action there is always an opposed or equal reaction; or, the mutual action of two bodies upon each other are always equal, and directed to contrary parts. The transducer reacts to applied forces and torque using Newton's third law.

Figure 2.2—Applied Force and Torque Vector on Transducer



The force applied to the transducer flexes three symmetrically placed beams using Hooke's law:

$$\sigma = E \cdot \epsilon$$

σ = Stress applied to the beam (σ is proportional to force)

E = Elasticity modulus of the beam

ϵ = Strain applied to the beam

NOTICE: The transducer is a monolithic structure. The beams are machined from a solid piece of metal. This decreases hysteresis and increases the strength and repeatability of the structure.

Semiconductor strain gages are attached to the beams and are considered strain-sensitive resistors. The resistance of the strain gage changes as a function of the applied strain as follows:

$$\Delta R = S_a \cdot R_0 \cdot \epsilon$$

ΔR = Change in resistance of strain gage

S_a = Gage factor of strain gage

R_0 = Resistance of strain gage unstrained

ϵ = Strain applied to strain gage

3. Installation

This section gives you information for the computer and system setup of the Digital F/T system.

3.1 Unpacking

- Check the shipping container and components for damage due to shipping. Any damage should be reported to ATI Industrial Automation.
- Check the packing list for omissions.
- The following are standard components for the Digital F/T system:
 - Transducer
 - Interface cable (9105-CF-MTS-DB9-X.X)
 - Serial Card and its CD
 - ATI CD containing software, calibration documentation, and manuals.



CAUTION: The transducer and serial card are susceptible to damage from electrostatic discharge whenever they are not connected to a plugged-in computer. Do not touch the electronics or the connector pins when handling the transducer.

3.2 Installing the Serial Card

Install the serial card hardware and its accompanying software following the instructions included with the hardware.

3.3 Configuring the Serial Card for Use with the Digital F/T System

Before using the Digital F/T with a National Instruments RS-485 serial interface, it is necessary to properly configure the communication and driver settings of the card for a two-wire interface and to use the card's FIFO buffers effectively:

3.3.1 Two Wire Communications

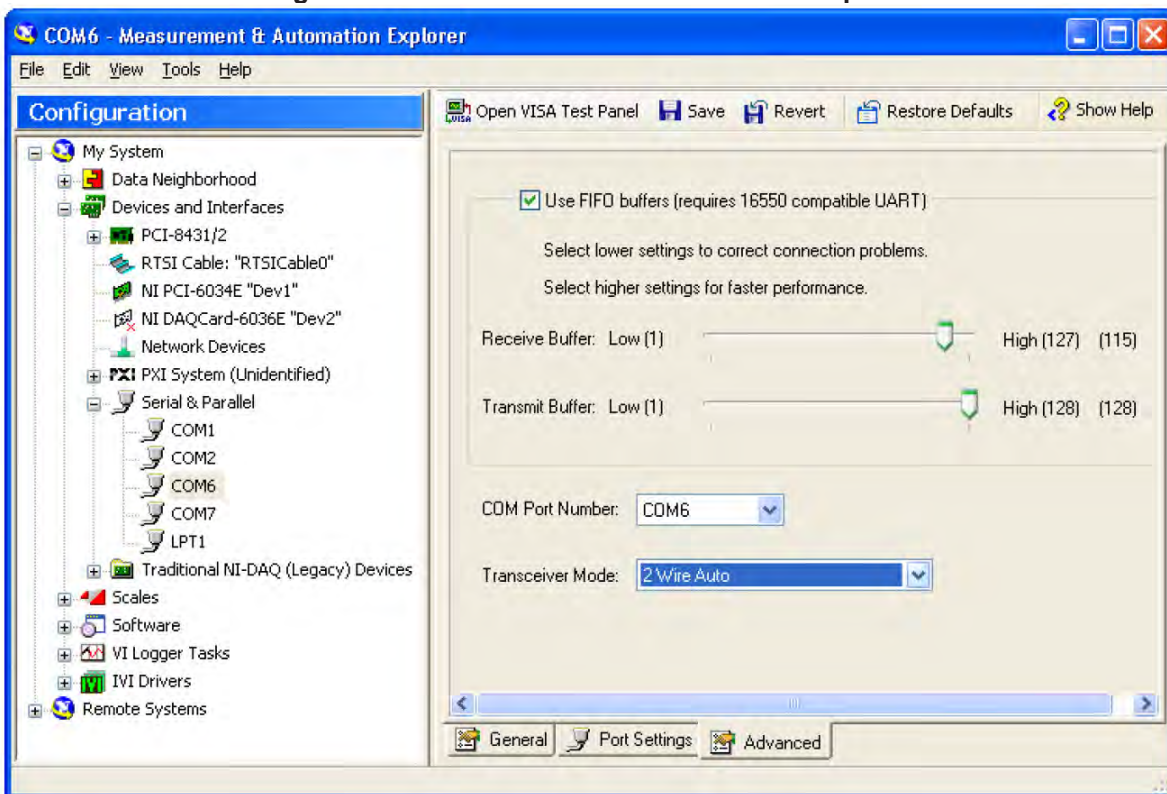
The Digital F/T control board uses a two-wire (half duplex) RS-485 connection. In this configuration, the same lines are used for transmitting and receiving data, therefore only one device at a time can transmit. Without proper configuration, this will also result in any data sent out by the master transmitter being echoed back to the master receiver, resulting in additional work for the software running on the master computer, as the echo will have to be read and discarded. National Instruments serial devices can be configured to automatically disable the receiver while transmitting to avoid receiving this echo.

3.3.2 FIFO Buffers

The National Instruments serial card has a hardware buffer that can hold up to 128 bytes. When the number of bytes in this hardware buffer reaches a configurable threshold, the card signals an interrupt so the client software can retrieve that data out of the hardware buffer. If the threshold level is set too close to the size of the hardware buffer, the client software may not finish pulling data out of the hardware buffer before the hardware buffer is completely filled up, resulting in lost data.

To configure the FIFO buffers and two wire communication, open Measurement and Automation Explorer for your serial card, select the serial device the sensor is to be connected to, open the “Advanced” properties panel, select the “2 Wire Auto” method in the “Transceiver Mode” pull down menu and set the FIFO buffer “Receive Buffer” threshold to a value lower than the maximum. The following example uses a threshold size of 64, which should work for most uses, but you can set the value higher or lower if you find your custom software has very specific timing requirements.

Figure 3.1—Measurement and Automation Explorer



In this configuration, the National Instruments serial device will disable the receiver while transmitting by default. If you have other software which requires the echo to be present in two-wire mode, or uses a four-wire (full duplex) connection, you will have to use one of the following methods:

- Use another serial interface for that software.
- Change the default Transceiver Mode every time you switch between the ATI software and your other software.
- Rewrite the other software to manually configure the NI serial interface for the correct mode when it is started. The NI-Serial help file details how manually configure the NI serial interface in the section “RS-485 Transceiver Control”.
- Write custom software for the Digital F/T that handles the echoed characters.
- Save MAX settings and close program.

3.4 Installing the Interface cable

Power down the computer with the serial card installed, ensure that computer is still plugged in. Before the transducer is installed, install the interface cable to the transducer and customer supplied power supply while set out on a clean work surface. Connect the interface cable to the transducer and power supply then to the serial card. After installing the interface cable the computer and power supply can be powered up.



CAUTION: The transducer and serial card are susceptible to damage from electrostatic discharge whenever they are not connected to a plugged-in computer. Do not touch the electronics or the connector pins when handling the transducer.



CAUTION: Do not exert excessive force on the transducer. The transducer is a sensitive instrument and can be damaged by applying force exceeding the single-axis overload values of the transducer and cause irreparable damage. Refer to the F/T Transducer Installation and Operation Manual (9620-05-Transducer Section) for transducer overload values.

3.5 Installing the software

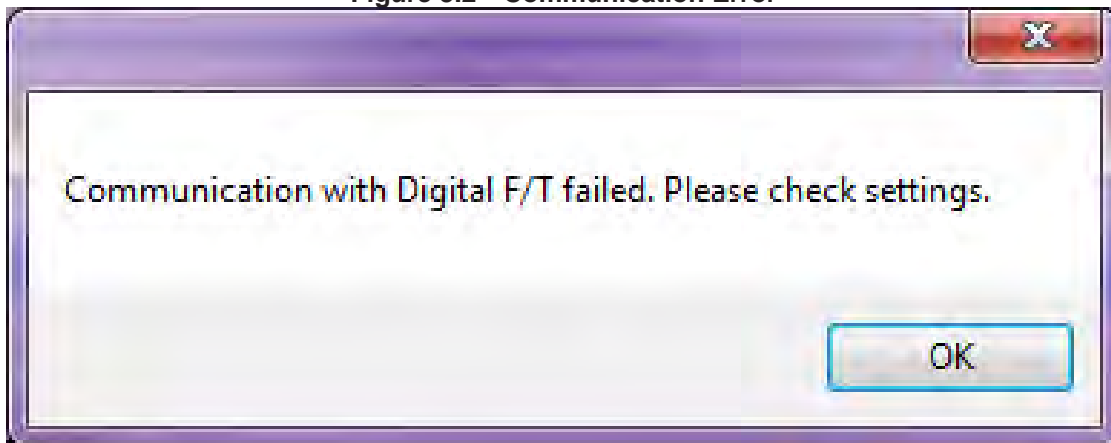
Install the ATI F/T software by inserting the CD into your computer. The installation program should start automatically. If it does not start automatically, you will need to run SETUP.EXE found in the root directory of the CD. Follow the installation instructions given by the program. The ATI F/T software CD contains software and calibration data that your computer uses to convert the transducer readings into usable force and torque output. It also contains Microsoft Windows drivers, sample programs, and detailed help files. The most recent release of the software can be downloaded from <http://www.ati-ia.com/Library/download.aspx>.

3.6 Demo Quick Start Guide:

The demo program monitors the raw strain gage values for saturation, when it is running. This will give feedback to help to avoid overloads and causing irreparable damage to the transducer. Smaller transducers can easily be irreparably damaged by applying small loads using tools (moment arm increases applied loads) when mounting the transducer.

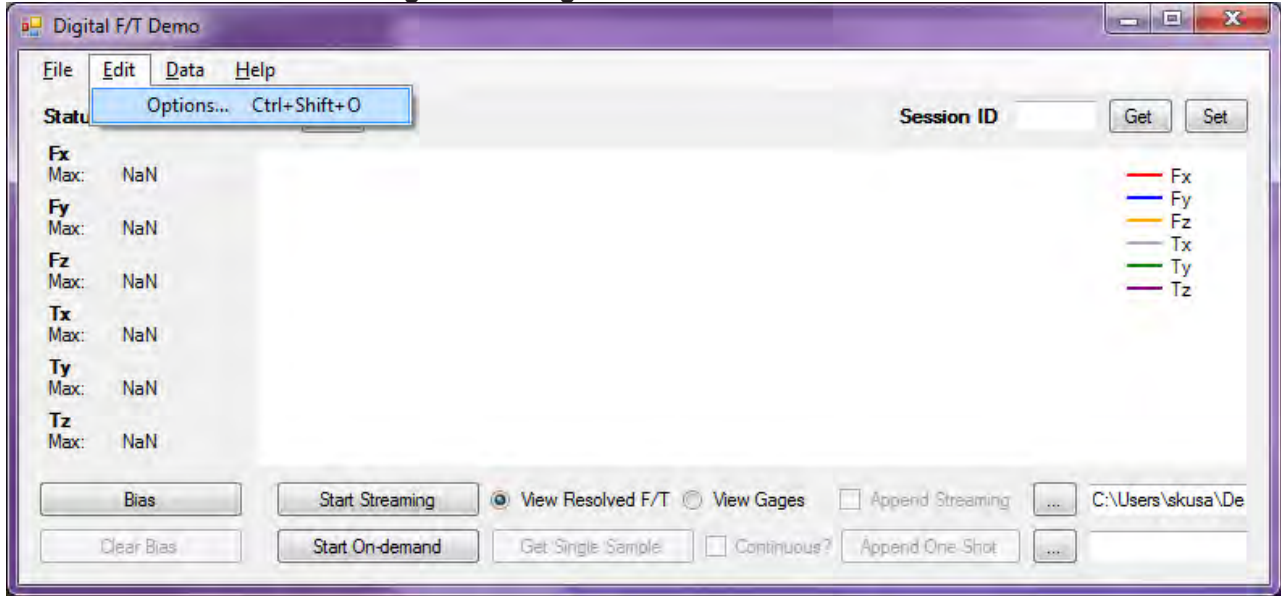
NOTICE: Each transducer has a maximum measurement range and a maximum overload capacity. **Exceeding the transducer's overload capacity can cause permanent damage.** Smaller transducers have lower overload capacities. Tx and Ty are usually the easiest axes to accidentally overload. Strain gage saturation is the first indication that you are approaching a mechanical overload condition, and saturation always causes inaccurate F/T data, so it is critical that you monitor the F/T system for strain gage saturation.

Figure 3.2—Communication Error



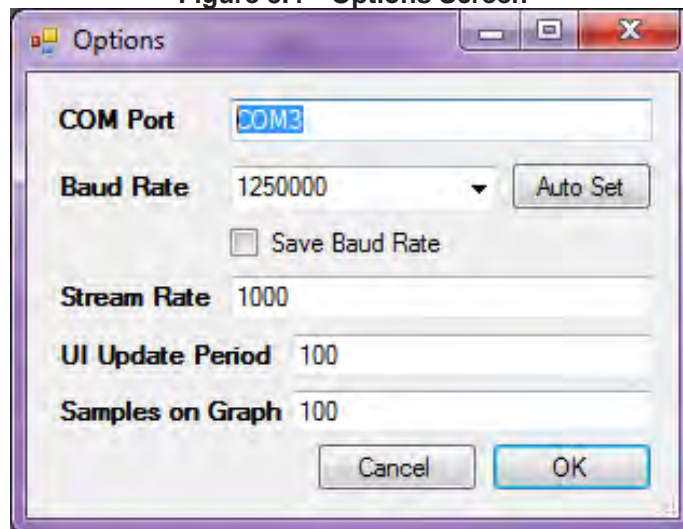
Open the demo software. The first time you run it, it will probably not be configured to talk to the correct port that you have connected the transducer to, and you will receive this message:

Figure 3.3—Digital F/T Demo Main Screen



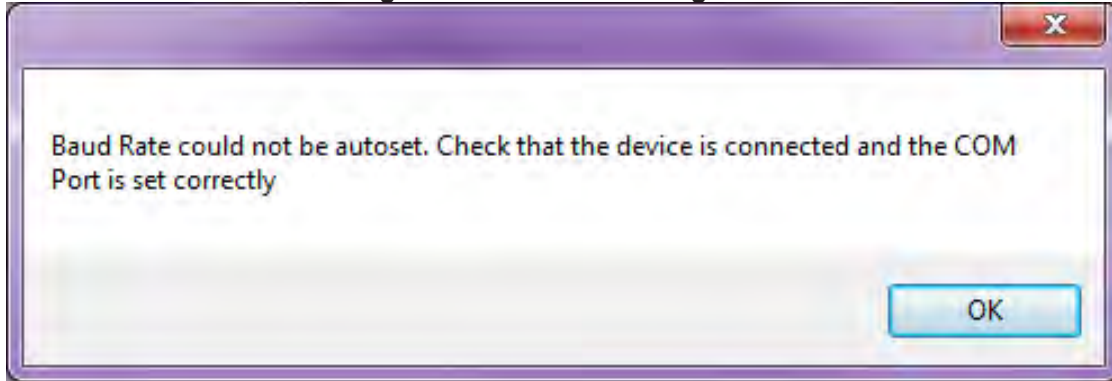
Open the “Edit”->”Options” menu item to enter the settings screen.

Figure 3.4—Options Screen



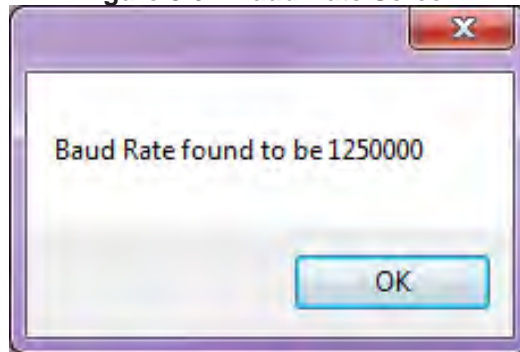
On the options screen, enter the name of the COM port you have the transducer connected to. If you are not sure which port on the serial card you have connected the transducer to, you may have to try more than one port name before you find the correct port name.

Figure 3.5—Start Streaming Data



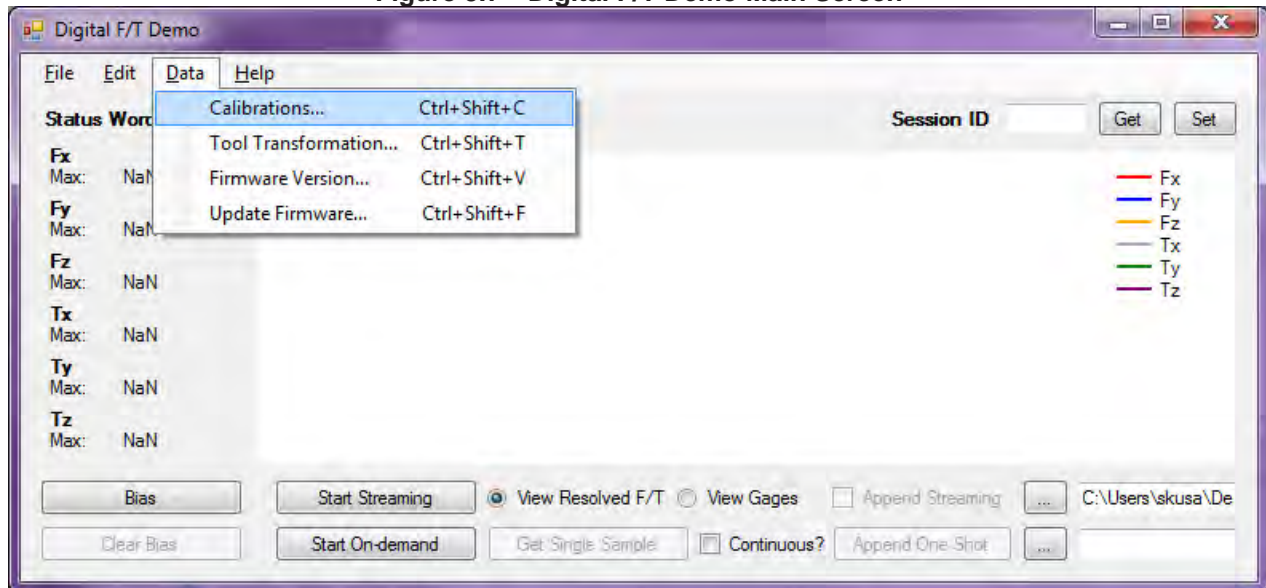
To test if the port you have entered is correct, press the “Auto Set” button next to the “Baud Rate” field. If you have entered the COM port wrong, or the sensor is disconnected or powered off, you will receive this message:

Figure 3.6—Baud Rate Screen



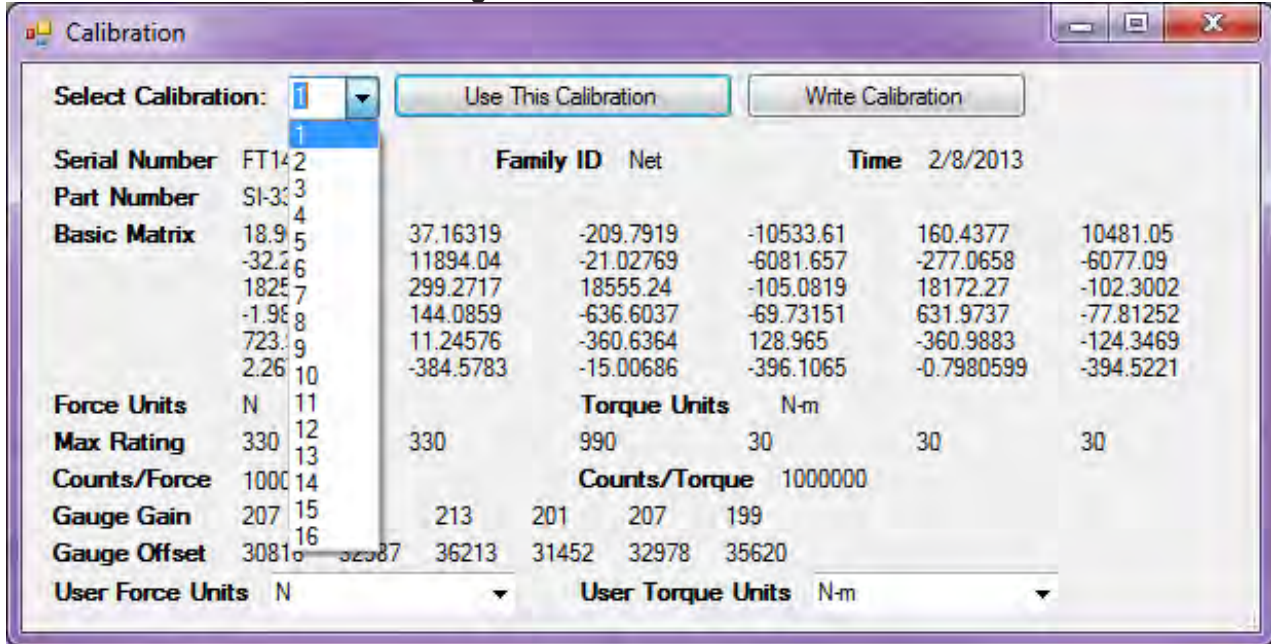
If the sensor is powered on and connected to the port you have entered, you will receive a success message like this:

Figure 3.7—Digital F/T Demo Main Screen



Press OK on the options screen to return to the main screen. Open the “Data”->”Calibrations” menu item to select the calibration:

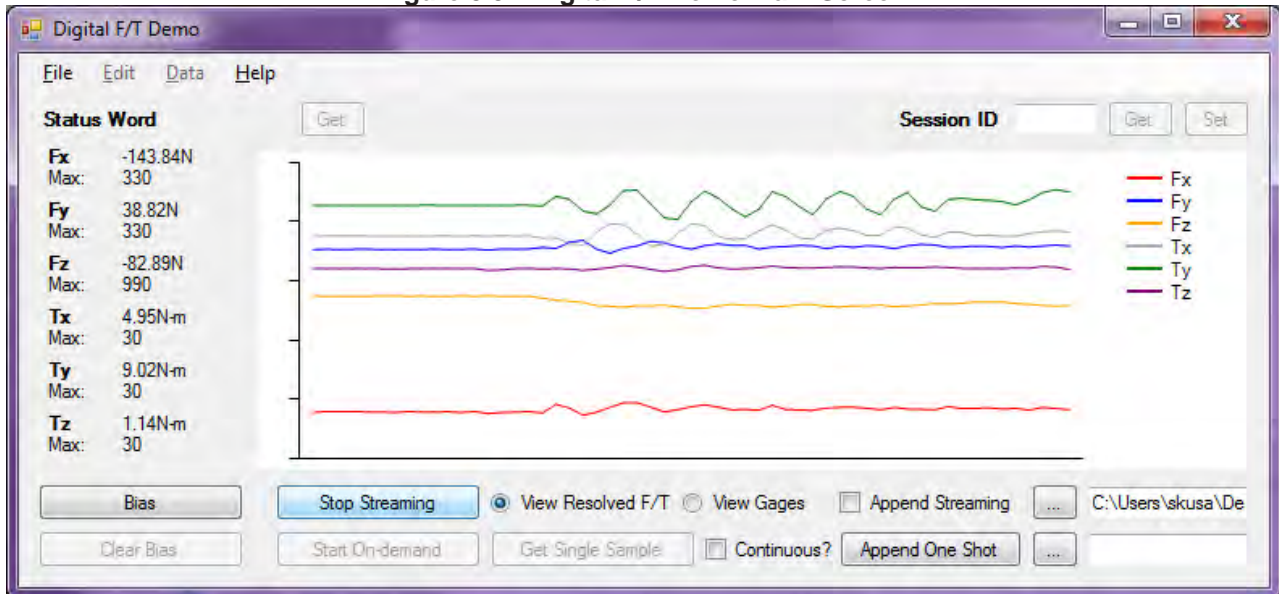
Figure 3.8—Calibration Screen



On the calibration screen, select the calibration index for the calibration you wish to activate from the “Select Calibration” pulldown. If you did not order multiple calibrations on your sensor, only the first calibration will have any data:

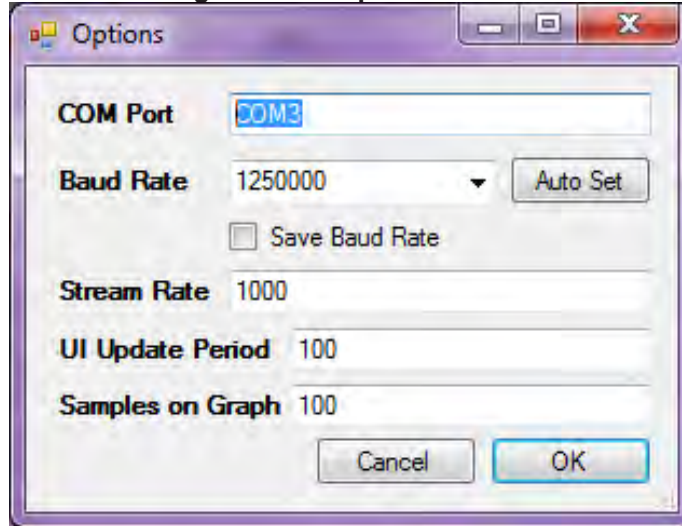
Once you have selected the calibration you wish to activate, click the “Use This Calibration” button to close the calibration screen and return to the main form.

Figure 3.9—Digital F/T Demo Main Screen



Click the “Start Streaming” or “Start On-Demand” button to start receiving data. If you press the “Start On-Demand” button, you can either press “Get Single Sample” when you wish to read a sample, or check the “Continuous” checkbox to have the demo automatically request data at the UI update period. Once you are receiving data, apply a gentle load to the sensor, being careful not to overload the sensor, to verify that you are able to read changes in the F/T data.

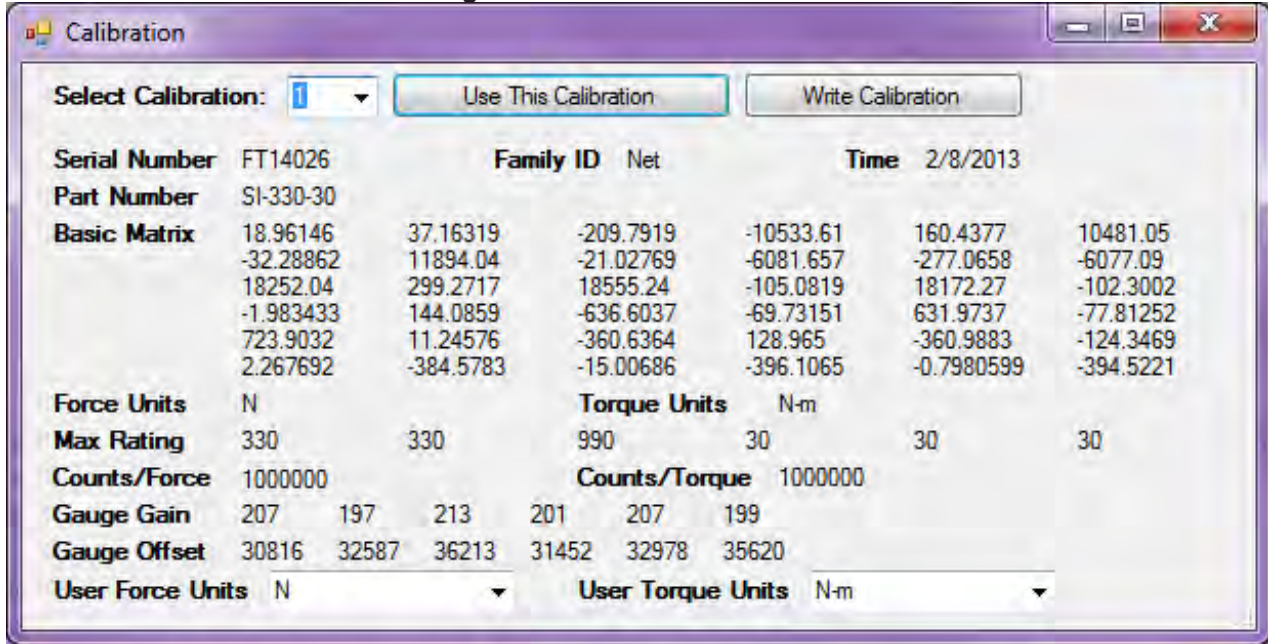
Figure 3.10—Options Screen



Option Screen Controls:

- **COM Port:** The name of the serial port the sensor is attached to.
- **Baud Rate:** The baud rate the sensor is configured for. Can be changed by the user.
- **Auto Set:** Will automatically scan all the available baud rates to see if the sensor is connected.
- **Save Baud Rate:** This checkbox must be checked before changing the baud rate in order for the new baud rate to be stored permanently during a power cycle.
- **Stream Rate:** The rate to configure the Digital F/T to stream data at. The maximum possible rates are 7000 at 1250000 baud, 500 at 115200 baud, and 50 at 19200 baud.
- **UI Update Period:** The number of milliseconds between UI updates. If “On-demand” sampling is selected, this is also the rate at which on-demand samples are requested from the sensor.
- **Samples On Graph:** The number of samples to keep in the history on the main screen graph.

Figure 3.11—Calibration Screen

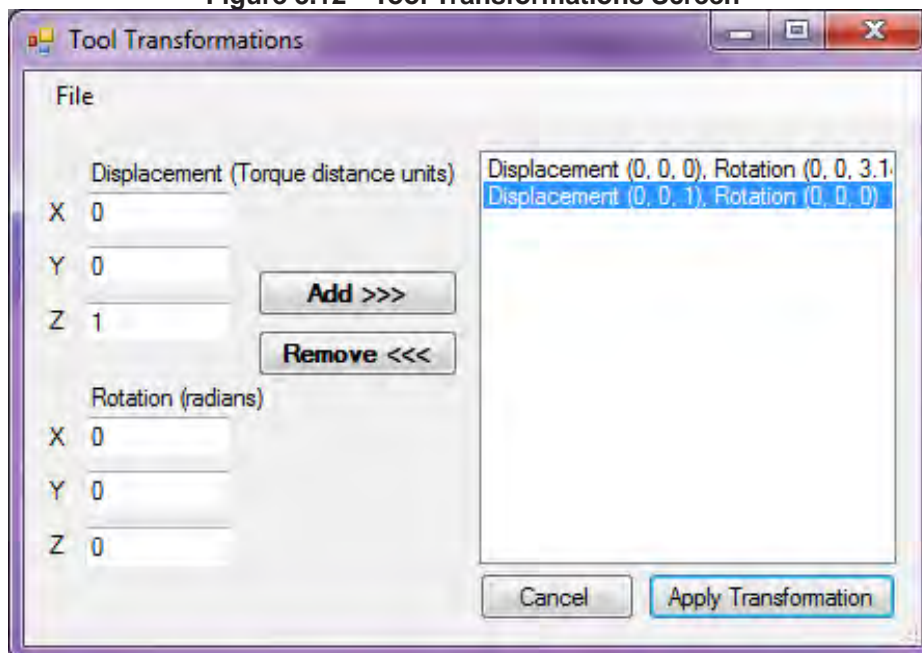


Calibration screen, available from the “Data”->”Calibrations” menu item on the main form.

Calibration Screen Controls:

- **Select Calibration:** This pulldown allows you to select the calibration to load into the sensor. If you did not order multiple calibrations for your sensor, only the first calibration will have any useful data.
- **Use This Calibration:** Activates the selected calibration and User Force and Torque Units and closes the form.
- **Write Calibration:** Prompts user for a calibration file, which can be loaded into the selected calibration index. This should only be used if the calibration data stored in the sensor becomes corrupted, and only the calibration file or files which were included on the CD with the sensor should be written to the sensor. Writing any calibration data that was not provided by ATI for your specific sensor will render the system uncalibrated.
- **User Force Units:** The force units to display on the main screen.
- **User Torque Units:** The torque units to display on the main screen.

Figure 3.12—Tool Transformations Screen



Tool Transformations Screen, available from “Data”->”Tool Transformations” menu item on main screen:

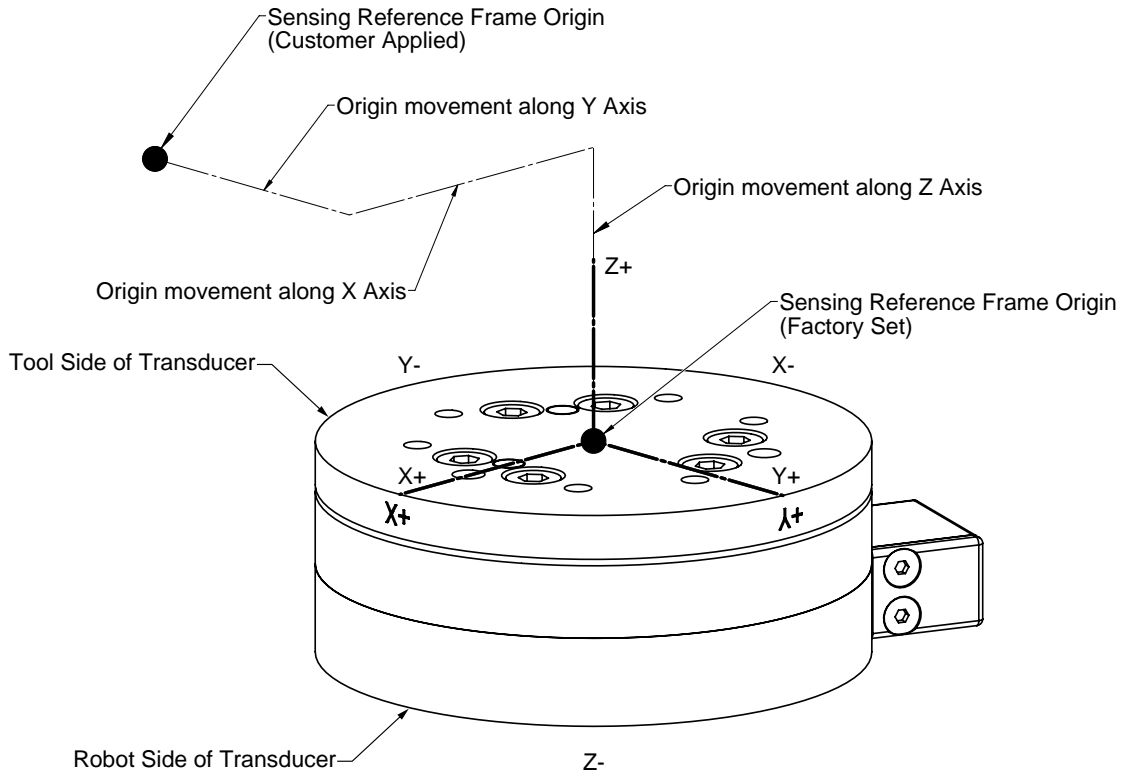
The tool transformation allows you to enter a series of tool transformations in order to measure the forces and torques acting at a point other than the origin of the sensor. The tool transformations are applied in the order you enter them, so you can determine, for example, if rotations occur before displacements by entering a tool transformation with only rotations before the rotation with displacements. If you specify both rotations and displacements within a particular tool transformation, displacements are performed first, in the order X, Y, Z, then rotations are performed, in the order X, Y, Z.

Tool Transformations Screen Controls:

- Displacement X, Y, and Z: The displacement along each axis is measured in the distance component of the calibration’s torque units, so if your sensor was calibrated to use Newton-meters as the torque unit, the displacement is measured in meters.
- Rotations X, Y, and Z: The rotation about each axis, in radians.
- Add: Adds the current tool transformation to the transformation queue.
- Remove: Removes the highlighted transformation from the queue, and fills the displacement and rotation controls with the values of the removed transformation.
- Cancel: Returns to the main form without applying any changes you made to the transformation queue.
- Apply Transformation: Applies transformations in the queue and returns to the main form.

Displacement allows the customer to move the sensing reference frame origin along the X, Y, and Z axes. Displacement should be calculated and values should be entered before rotation. Displacement is measured in units which are set as either Nm or in-lbs. on the Calibration Screen. Refer to [Figure 3.8](#).

Figure 3.13—Displacement of Sensing Reference Frame Origin



Rotation allows the customer to rotate the axes while maintaining the frame origin. [Figure 3.14](#) shows the direction of rotation about the axis. Rotation is measured in radians.

When a value is entered for X, Y, or Z the following will result:

- X value will rotate Y and Z about X in the direction shown (see [Figure 3.14](#)).
- Y value will rotate X and Z about Y in the direction shown.
- Z value will rotate X and Y about Z in the direction shown.

In a tool transformation, the order of the rotations matters. The X-rotation occurs first, followed by rotation about Y (in its new orientation), then Z. Therefore, you **MUST** express your rotations in this order.

Figure 3.14—Rotating Reference Frame

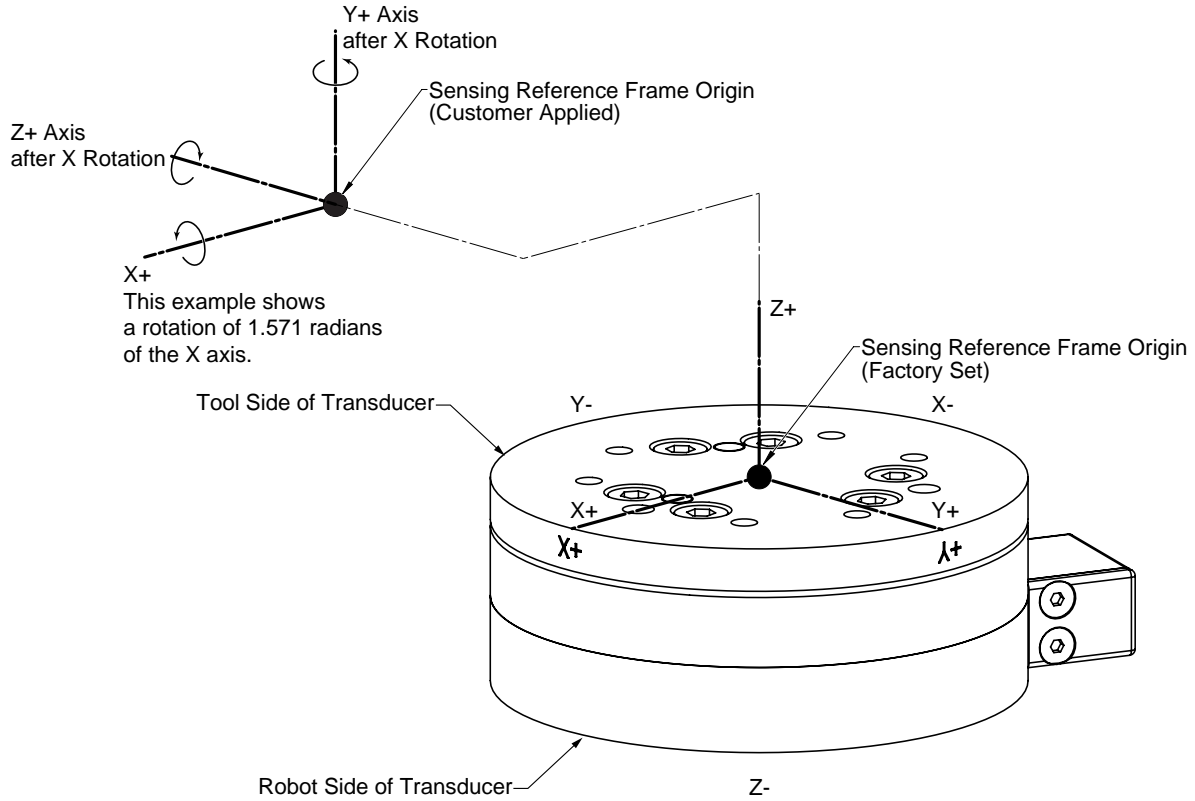
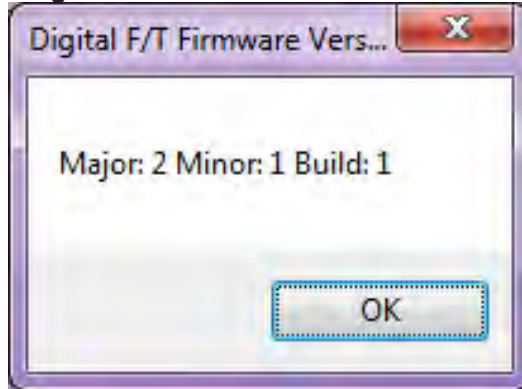


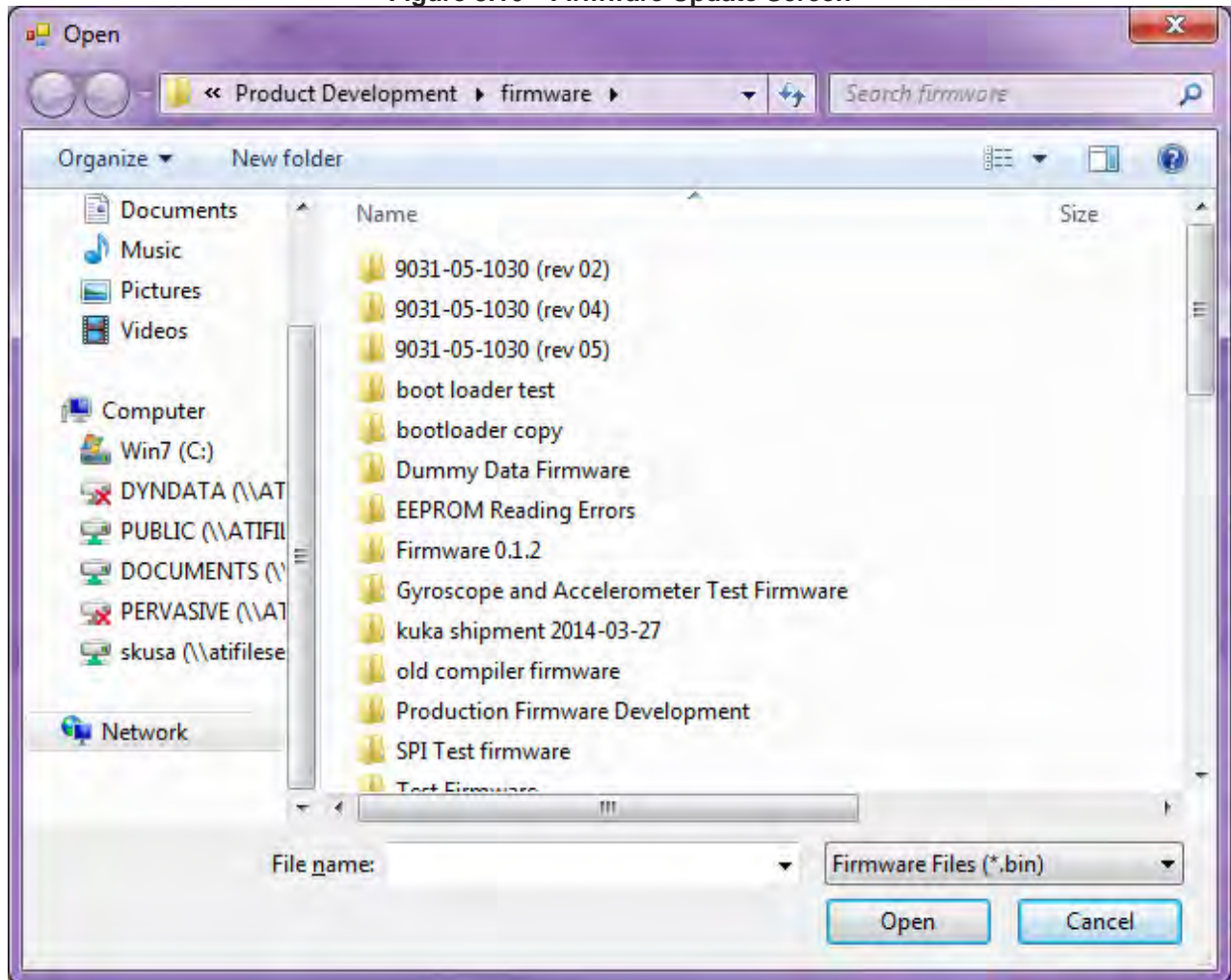
Figure 3.15—Firmware Version Screen



Firmware Version screen, available from “Data”->”Firmware Version” menu item on the main form.

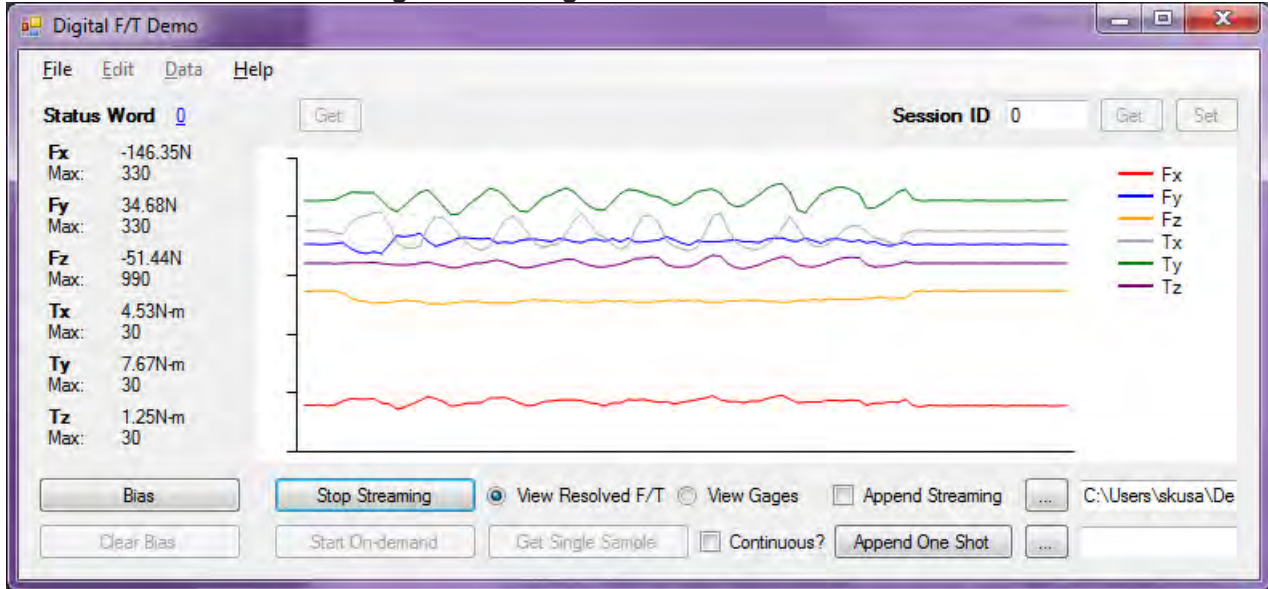
This screen shows the current firmware installed on the sensor. Press the OK button to dismiss and return to the main form.

Figure 3.16—Firmware Update Screen



You can use this to update the firmware on the Digital F/T. Only firmware files distributed from ATI for your specific device should be uploaded. The use of any other kind of file will render the sensor permanently inoperable.

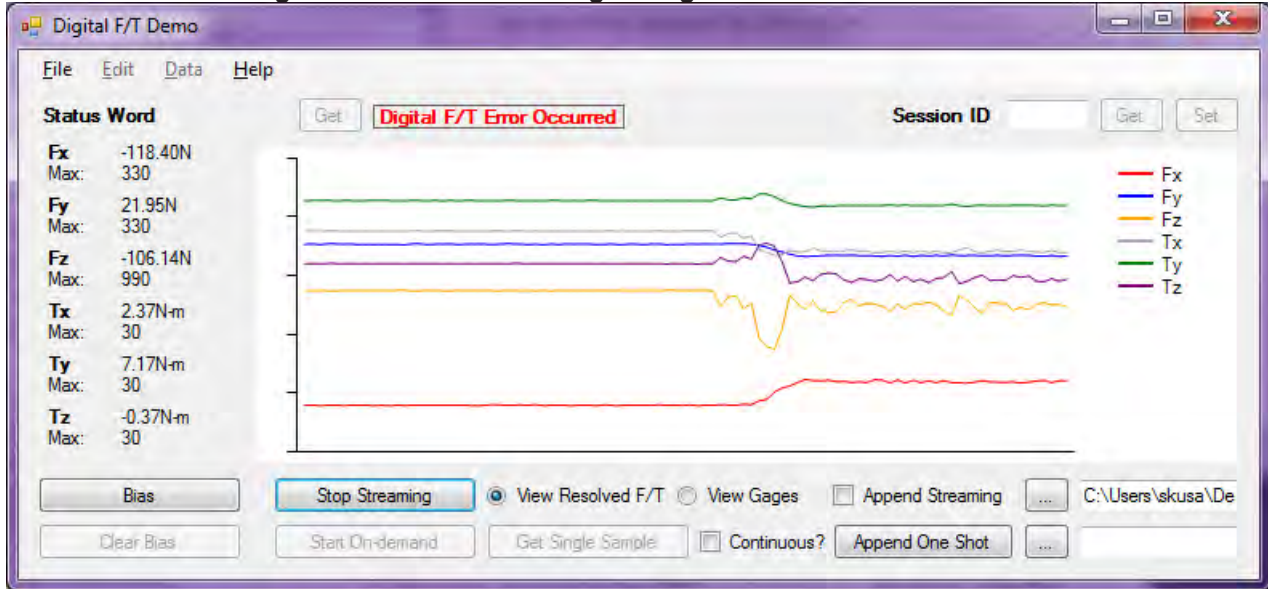
Figure 3.17—Digital F/T Demo Main Screen



Main Screen Controls:

- Bias: Takes the current reading and subtracts it from all future readings, using the current load as a tare.
- Clear Bias: Removes all previous tare points, so the sensor readings are raw outputs.
- Start Streaming/Stop Streaming: Toggles the streaming output of the sensor. When streaming, the sensor sends data at the frequency specified in the Streaming Rate field on the Options screen.
- Start On-demand/Stop On-demand: Toggles the on-demand output of the sensor. When the sensor is in on-demand mode, it outputs data only in response to requests from the user. This is useful for getting data at exact points in time.
- View Resolved F/T / View Gages: Switches the display and collected data between force/torque values and strain gages. The strain gage data is useful for diagnostic purposes if you ever have to call ATI Industrial Automation for support.
- Get Single Sample: When in on-demand mode, you can press this button to read a single sample and display it. The demo will not read another sample until you press the Get Single Sample button again, or activate another mode of reading data by using the Start Streaming button or the “Continuous?” checkbox.
- Continuous? : When in on-demand mode, the continuous checkbox causes the demo to request samples every time the UI updates.
- Append Streaming: When in streaming mode, activate this checkbox to append streaming data samples read from the sensor to the file specified next to the Append Streaming checkbox.
- Append One Shot: When in streaming or on-demand mode, this button is available to append only the most recent sample to the file specified next to the Append One Shot button.
- Status Word – Get button: Reads the current status word from the sensor and displays it. Clicking on the status word will bring up a window describing the meaning of any error codes present in the status word.
- Session ID – Get Button: Reads the current session ID.
- Session ID – Set Button: Write the value in the session ID field to the sensor’s session ID. The session ID is useful in automated applications to make sure the sensor has not been reset.

Figure 3.18—Error Handling on Digital F/T Demo Main Screen



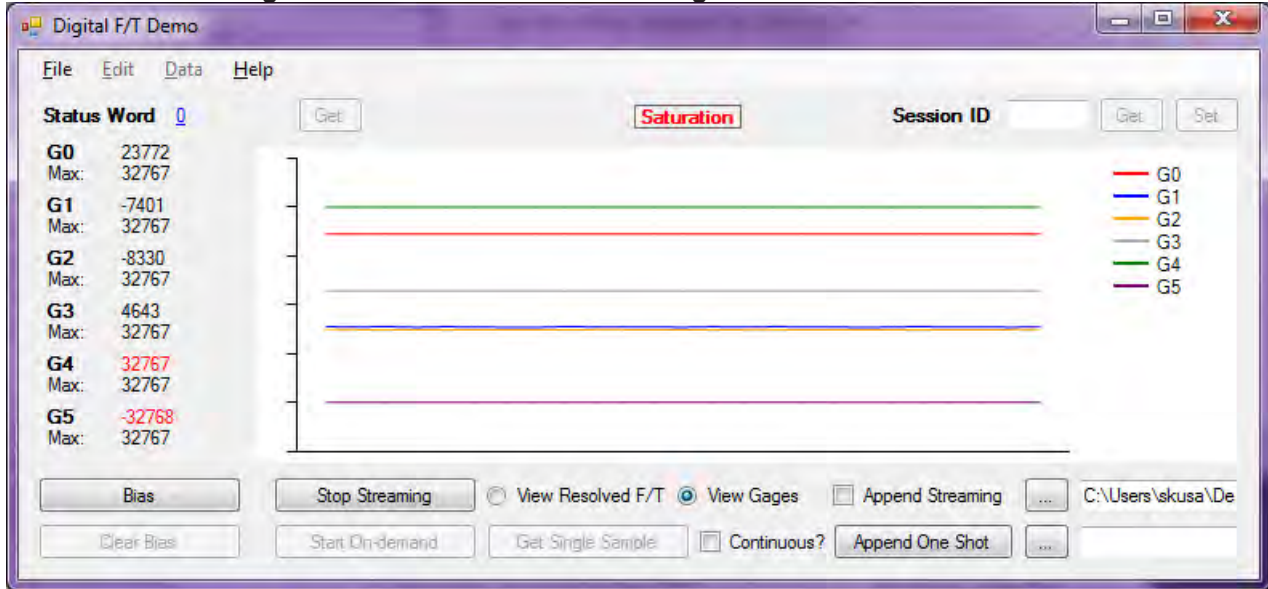
The text “Digital F/T Error Occurred” appears when a sample is read that contains an error bit. To determine the actual error code, you must stop streaming or on-demand mode and click the Status Word – Get button:

Figure 3.19—Firmware Version Screen



Once you have read the Status Word, clicking on the code will bring up a window telling you what the error code means:

Figure 3.20— Saturation Error on Digital F/T Demo Main Screen



Saturation occurs whenever one or more gages is saturated. You can determine which gages are saturated by selecting “View Gages” and looking for gage values that are either 32767 or -32768 counts. These gage values will be highlighted in red.

NOTICE: When any strain gage is saturated or otherwise inoperable, **all transducer F/T readings are invalid.**

3.7 Installing the Transducer

Information on transducer installation can be found in the F/T Transducer Manual, 9620-05-Transducer Section, *F/T Transducer Installation, Operation, and Specification Manual*.

4. Operation

This section gives you information for the operation of the Digital F/T system.

4.1 Multiple Calibrations

Some transducers have multiple calibrations, usually to allow the transducer to have larger range in one instance and finer resolution in another. Changing to another calibration is done by loading the new calibration. This is done in the demo software through the *Data/Calibration* menu item.

NOTICE: When any strain gage is saturated or otherwise inoperable, all transducer F/T readings are invalid.

4.2 Detecting Sensitivity Changes

Sensitivity checking of the transducer can also be used to measure the transducer system's health. This is done by applying known loads to the transducer and verifying the system output matches the known loads. For example, a transducer mounted to a robot arm may have an end-effector attached to it.

If the end-effector has moving parts, they must be moved in a known position. Place the robot arm in an orientation that allows the gravity load from the end-effector to exert load on many transducer output axes.

Record the output readings.

Position the robot arm to apply another load, this time causing the outputs to move far from the earlier readings.

Record the second set of output readings.

Find the differences from the first and second set of readings and use it as your sensitivity value.

Even if the values vary somewhat from sample set to sample set, they can be used to detect gross errors. Either the resolved outputs or the raw transducer voltages may be used (the same must be used for all steps of this process).

5. Maintenance

This section gives you information for the maintenance of the Digital F/T system.

5.1 Periodic Inspection

For most applications, there are no parts that need to be replaced during normal operation. With industrial-type applications that continuously or frequently move the system's cabling, you should periodically check the cable jacket for signs of wear.

The transducer must be kept free of excessive dust, debris, or moisture. Applications with metallic debris (i.e., electrically-conductive) must protect the transducer from this debris. Transducers without specific factory-installed protection are to be considered unprotected. The internal structure of the transducers can become clogged with particles and will become no longer calibrated or even damaged.

5.2 Periodic Calibration

Periodic calibration of the transducer is required to maintain traceability to national standards. Follow any applicable ISO-9000-type standards for calibration. ATI recommends annual calibrations, especially for applications that frequently cycle the loads applied to the transducer.

5.3 Resolution

ATI's transducers have a three sensing beam configuration where the three beams are equally spaced around a central hub and attached to the outside wall of the transducer. This design transfers applied loads to multiple sensing beams and allows the transducer to increase its sensing range in a given axis if a counterpart axis has reduced (see 9620-05-Transducer Section—Installation and Operation Manual).

The resolution of each transducer axis depends on how the applied load is spread among the sensing beams. The best resolution occurs in the scenario when the quantization of the gages is evenly distributed as load is applied. In the worst case scenario, the discrete value of all involved gages increases at the same time. The typical scenario will be somewhere between these two.

F/T resolutions are specified as typical resolution, defined as the average of the worst and best case scenarios. Because both multi-gage effects can be modeled as a normal distribution, this value represents the most commonly perceived, average resolution. Although this misrepresents the actual performance of the transducers, it results in a close (and always conservative) estimate.

6. Troubleshooting

Bad data from the transducer's strain gages can cause errors in force/torque readings. These errors can result in problems with transducer biasing and accuracy. Listed below are the basic conditions of bad data. Use this to troubleshoot your problem.

Symptom	Cause	Resolution
Noise	Noise can be caused by mechanical vibrations and electrical disturbances, possibly from a poor ground. It can also indicate component failure within the system.	Make sure that the DC supply voltage for the Digital F/T has little to no noise superimposed.
Drift	Drift is caused by temperature change, mechanical coupling, or internal failure. Mechanical coupling is caused when a physical connection is made between the tool plate and the transducer body (i.e., filings between the tool adapter plate and the transducer body).	Check for debris around transducer.
Hysteresis	Hysteresis is caused by mechanical coupling (explained in Drift section) or internal failure.	Check for debris around transducer.

If, after configuring the NI Serial device for two-wire RS485 mode, the Digital FT does not respond to commands, it is possible you have encountered a bug in the National Instruments driver software whereby the correct transceiver mode is not always activated. Make sure you have installed the latest NI Serial driver software from www.ni.com. If you are experienced with using an oscilloscope, it will be helpful to make sure that the transmit lines on the NI Serial device are actually activating when the software tries to send data. If the card is transmitting correctly, but the sensor is not responding, contact ATI for support with the Digital FT. If the card does not transmit when in "2 Wire Auto" transceiver mode, and you have the latest NI Serial software, try putting the card and NI Serial software in another computer and attempting to use it in the other computer. If it still does not work, you may have to contact National Instruments for support with the NI Serial device.

7. Specifications

7.1 Storage and Operating Conditions

Table 7.1—Temperature		
Component	Storage Temperature, °C	Operating Temperature, °C
Digital F/T	-40 to +100	-20 to +70
Transducer	See Transducer Section Manual http://www.ati-ia.com/app_content/documents/9620-05-Transducer%20Section.pdf	See Transducer Section Manual http://www.ati-ia.com/app_content/documents/9620-05-Transducer%20Section.pdf

8. Programming Information

This section contains programming information about the Digital F/T System.

8.1 Physical Serial Interface

The interface cable by default runs at 1.25 megabaud. The baud rate can also be set to 115,200 or 19,200, although this will result in slower streaming output rates.

Baud Rate	Streaming Sample Speed
1,250,000	7000 Hz
115,200	500 Hz
19,200	100 Hz

The interface cable uses a two-wire half-duplex configuration – the sensor cannot receive bytes while it is writing. Therefore, to stop streaming, it is necessary to send a jamming sequence of at least 14 characters, which is one byte longer than a streaming sample.

The transducer uses a 9-bit format with 8 bits of data and the last bit used for ‘even’ parity.

8.2 Data Types

This section gives the definitions for the different data types used.

Term	Definition
float	IEEE 754-2008 binary32 (aka ‘single’) floating point number.
int16	16-bit signed integer
int32	32-bit signed integer
uint8	8-bit unsigned integer
uint16	16-bit unsigned integer

8.3 Modbus Interface

The Modbus interface follows the timing and checksum rules specified in the “Modbus Over Serial Line” specification at <http://www.modbus.org/specs.php>.

The analog board runs as a Modbus slave until the ‘start streaming’ custom Modbus command is sent, after which it starts streaming data until it receives a 14-byte jamming sequence (the jamming sequence can consist of random character values).

If you are writing your own Modbus interface to the Digital F/T, you must support the “Read Holding Registers” (Section 6.3 in the “Modbus Protocol Specification” v1.1b) command and one or both of the “Write Single Register” (Section 6.6) and “Write Multiple Registers” (Section 6.12) commands. You must also be able to send Custom (aka “User-Defined”) function codes.

Each serial Modbus packet has the following structure (taken from Section 2.3 of the “Modbus Serial Line Protocol and Implementation Guide” v1.02):

Address Field (always 10 for Digital F/T)	Function Code	Data (may be up to 252 bytes and contain a structure with multiple fields)	CRC High Byte	CRC Low Byte
---	---------------	--	---------------	--------------

The sensor uses a fixed Modbus slave address of 10, and only communicates using the binary “RTU” serial Modbus packet format. The CRC calculation for the binary RTU mode, including sample source code, is described in Section 6.2.2 of the “Modbus Serial Line Protocol and Implementation Guide” v1.02.

8.3.1 Custom Service Codes

Each custom service code uses the same serial Modbus command and response format:

Slave Address (10)	Function Code Command: The function code to execute. Response: The function code executed (same as command).	Data	CRC High Byte	CRC Low Byte
--------------------	--	------	---------------	--------------

Table 8.3—Custom Service Codes

Code	Description	Data	Response
106	Unlock storage command: Use this function code before writing gains and offsets for selected calibration.	1 data byte – 0xaa to unlock, 0x18 to lock.	A Modbus packet with one data byte of value 1 for successful execution, or a standard Modbus error packet if unsuccessful.
70	Start strain gage streaming	1 data byte with value 0x55.	A Modbus packet with one data byte with value 1 for successful reception, or a standard Modbus error packet if unsuccessful. After successful reception of a command to start strain gage streaming, the sensor will delay for 20 ms to give the client time to disable the Modbus protocol. After this 20 ms delay, the sensor will begin sending out streaming data samples that are not encapsulated in Modbus frames.

8.3.2 Important Holding Register Addresses

Addresses are base 0:

Table 8.4—Important Holding Register Addresses									
Address	Description								
0x00e3	Calibration 1								
0x01a3	Calibration 2								
0x0263	Calibration 3								
0x0323	Calibration 4								
0x03e3	Calibration 5								
0x04a3	Calibration 6								
0x0563	Calibration 7								
0x0623	Calibration 8								
0x06e3	Calibration 9								
0x07a3	Calibration 10								
0x0863	Calibration 11								
0x0923	Calibration 12								
0x09e3	Calibration 13								
0x0aa3	Calibration 14								
0x0b63	Calibration 15								
0x0c23	Calibration 16								
0x001D	Status Word								
0x0000-0x0005	Active Gain pots								
0x0006-0x000B	Active Offset DACs								
0x000C	Optional “Session ID” register								
0x001F	Baud Rate Register. Values: <table border="1" data-bbox="699 1205 1128 1369"> <thead> <tr> <th>Register Value</th> <th>Baud Rate</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>1,250,000</td> </tr> <tr> <td>1</td> <td>19,200</td> </tr> <tr> <td>2</td> <td>115,200</td> </tr> </tbody> </table> <p>The value is only stored to non-volatile memory if bit 0 of the “Mode” register is a ‘1’. Baud rate changes take effect immediately.</p>	Register Value	Baud Rate	0	1,250,000	1	19,200	2	115,200
Register Value	Baud Rate								
0	1,250,000								
1	19,200								
2	115,200								
0x001E	Mode Register. Set bit 0 of this register to a ‘1’ in order to save changes to the baud rate. The mode bit must be set before the baud rate is changed in order to save the new baud rate.								

8.4 Data Structures

8.4.1 Endianness

The Digital F/T stores all numbers in big-endian (aka “Network Order”) format. If your host system uses a little-endian (“Byte-swapped”) format, any custom software you write will have to swap the bytes in each numeric field before performing any calculations using those values.

8.4.2 Streaming Sample Format

```
{  
  int16 G0;  
  int16 G2;  
  int16 G4;  
  int16 G1;  
  int16 G3;  
  int16 G5;  
  uint8 check;  
}
```

The fields G0–G5 make up the gage vector. When calculating F/T values, this vector is multiplied with the calibration matrix using the standard matrix multiplication algorithm.

NOTICE: The strain gages are sent in the order (G0, G2, G4, G1, G3, G5), and must be reordered to (G0, G1, G2, G3, G4, G5) before performing F/T calculations (or the calibration matrix itself can be reordered to accommodate the streaming sample ordering). The streaming sample is structured this way in order to sample the gages which cooperate on the most axes as close together as possible.

The ‘check’ field is a single byte containing a checksum and a status bit:

Bit Number	Meaning
0–6	Additive checksum
7	Status

The additive checksum can be calculated using the following algorithm. The ‘&’ operator in the following pseudocode indicates a bitwise ‘and’ operation, and the ‘sampleBytes’ parameter contains the 13 bytes that make up a streaming sample packet.

```

CheckSample( sampleBytes:array of bytes ) : true/false
    checksum = 0
    for i = 0 to 11
        checksum = checksum + sampleBytes[i]
    next i
    if ( checksum & 0x7f ) <> ( sampleBytes[12] & 0x7f )
        return false      /* checksum does not match. */
    else
        return true       /* checksum matches. */
    end if
    
```

The status bit is 0 if the system is healthy, or 1 if there is an error code. If the status bit indicates an error, stop streaming by sending a jamming sequence of 14 bytes, then use standard Modbus to read the system status holding register to get the full error code. The jamming sequence can consist of arbitrary values, any character value will stop streaming.

Since there is no contingency in Modbus for high-speed streaming data, the streaming samples are not sent in standard Modbus packets – they are sent without any encapsulation. This requires the client software to disable any Modbus processing of received packets while data streaming is active.

8.4.3 Status Word

The status word is a bitmap which contains information about the errors that can occur in various subsystems of the Digital F/T sensor:

Bit Number	Meaning If Set
0	Watchdog reset – the analog board was reset by the watchdog timer.
1	Excitation voltage too high.
2	Excitation voltage too low.
3	Artificial analog ground out of range.
4	Power supply too high.
5	Power supply too low.
6	Not used.
7	Error accessing stored settings in EEPROM.
8	Invalid configuration data.
9	Strain gage bridge supply current too high.
10	Strain gage bridge supply current too low.
11	Thermistor too high.
12	Thermistor too low.
13	DAC reading out of range.
14	Not used.
15	Any error sets this bit.

8.4.4 Calibration Structure

Calibration data is read using standard Modbus holding register read commands. You cannot write data to the calibration structures.

```
{  
    uint8 CalibSerialNumber[8];  
    uint8 CalibPartNumber[32];  
    uint8 CalibFamilyId[4];  
    uint8 CalibTime[20];  
    float BasicMatrix[6][6];  
    uint8 ForceUnits;  
    uint8 TorqueUnits;  
    float MaxRating[6];  
    int32 CountsPerForce;  
    int32 CountsPerTorque;  
    uint16 GageGain[6];  
    uint16 GageOffset[6];  
    uint8 Resolution[6];  
    uint8 Range[6];  
    uint16 ScaleFactor16[6];  
    uint8 UserField1[16];  
    uint8 UserField2[16];  
    uint8 SpareData[16];  
}
```


Table 8.7—Calibration Structure Fields															
Address	Description														
CalibSerialNumber	The serial number of the calibration as a null-terminated ASCII string.														
CalibPartNumber	The ATI part number of the calibration as a null-terminated ASCII string.														
CalibFamilyID	The ATI Calibration family as a null-terminated ASCII string.														
CalibTime	The date the calibration was released as a null-terminated ASCII string in a format like '1970-01-01 00:00:00'.														
BasicMatrix	The calibration matrix. Multiply this matrix with the gage vector to get a vector containing the force and torque values.														
ForceUnits	An integer which encodes the force units of the calibration. <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="text-align: center;">Code</th> <th style="text-align: center;">Force Unit</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">1</td> <td style="text-align: center;">Pound</td> </tr> <tr> <td style="text-align: center;">2</td> <td style="text-align: center;">Newton</td> </tr> <tr> <td style="text-align: center;">3</td> <td style="text-align: center;">Kilopound</td> </tr> <tr> <td style="text-align: center;">4</td> <td style="text-align: center;">KiloNewton</td> </tr> <tr> <td style="text-align: center;">5</td> <td style="text-align: center;">Kilogram-equivalent force</td> </tr> <tr> <td style="text-align: center;">6</td> <td style="text-align: center;">Gram-equivalent force</td> </tr> </tbody> </table>	Code	Force Unit	1	Pound	2	Newton	3	Kilopound	4	KiloNewton	5	Kilogram-equivalent force	6	Gram-equivalent force
Code	Force Unit														
1	Pound														
2	Newton														
3	Kilopound														
4	KiloNewton														
5	Kilogram-equivalent force														
6	Gram-equivalent force														
TorqueUnits	An integer which encodes the torque units of the calibration. <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="text-align: center;">Code</th> <th style="text-align: center;">Force Unit</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">1</td> <td style="text-align: center;">Pound-inch</td> </tr> <tr> <td style="text-align: center;">2</td> <td style="text-align: center;">Pound-foot</td> </tr> <tr> <td style="text-align: center;">3</td> <td style="text-align: center;">Newton-meter</td> </tr> <tr> <td style="text-align: center;">4</td> <td style="text-align: center;">Newton-millimeter</td> </tr> <tr> <td style="text-align: center;">5</td> <td style="text-align: center;">Kilogram(-equivalent)-centimeter</td> </tr> <tr> <td style="text-align: center;">6</td> <td style="text-align: center;">KiloNewton-meter</td> </tr> </tbody> </table>	Code	Force Unit	1	Pound-inch	2	Pound-foot	3	Newton-meter	4	Newton-millimeter	5	Kilogram(-equivalent)-centimeter	6	KiloNewton-meter
Code	Force Unit														
1	Pound-inch														
2	Pound-foot														
3	Newton-meter														
4	Newton-millimeter														
5	Kilogram(-equivalent)-centimeter														
6	KiloNewton-meter														
MaxRating	The maximum rated load of each axis, in the order [Force X, Force Y, Force Z, Torque X, Torque Y, Torque Z].														
CountsPerForce	The counts per unit force of the calibration.														
CountsPerTorque	The counts per unit torque of the calibration.														
GageGain	The gain values used for each of the six strain gages in this calibration.														
GageOffset	The offset values used for each of the six strain gages in this calibration.														
Resolution	Not used in this product.														
Range	Not used in this product.														
ScaleFactor	Not used in this product.														
UserField1	Not used in this product.														
UserField2	Not used in this product.														
SpareData	Not used in this product.														

Each calibration structure is 338 bytes long, so to read the settings for a particular calibration, start at the address of the desired calibration from [Table 8.4](#) and read 169 holding registers, since each register is two bytes wide. It will be necessary to split the reading up into multiple Modbus commands, due to length restrictions in the Modbus protocol.

8.5 Tool Transformations

A tool transformation is a mathematical procedure that allows you to calculate the force and torque values that are acting at a point other than the origin of the sensor itself, and also allows you to rotate the reference frame, for example to line up the sensor axes with your tooling axes. The transformation is calculated by applying rotation and translation matrices to the original calibration matrix (the “BasicMatrix” element of the calibration structure).

In general, the transform takes the following form:

Equation 1

$$[R]_{6 \times 6} [D]_{6 \times 6} [C]_{6 \times 6} [G]_{6 \times 1} = [F]_{6 \times 1}$$

Where:

R = Rotation matrix

D = Displacement (translation) matrix

C = Calibration matrix

G = Raw gage values

F = Resolved force/torque values

The rotation matrix is defined as:

$$R = \begin{bmatrix} cy \cdot cz & sx \cdot sy \cdot sz + cx \cdot sz & sx \cdot sz - cx \cdot sy \cdot cz & 0 & 0 & 0 \\ -cy \cdot sz & -sx \cdot sy \cdot sz + cx \cdot cz & sx \cdot cz + cx \cdot sy \cdot sz & 0 & 0 & 0 \\ sy & -sx \cdot cy & cx \cdot cy & 0 & 0 & 0 \\ 0 & 0 & 0 & cy \cdot cz & sx \cdot sy \cdot sz + cx \cdot sz & sx \cdot sz - cx \cdot sy \cdot cz \\ 0 & 0 & 0 & -cy \cdot sz & -sx \cdot sy \cdot sz + cx \cdot cz & sx \cdot cz + cx \cdot sy \cdot sz \\ 0 & 0 & 0 & sy & -sx \cdot cy & cx \cdot cy \end{bmatrix}$$

Where “s” and “c” indicate the sin and cosine operations respectively, and “x”, “y”, and “z” are the rotations about the x, y, and z axes respectively.

This displacement matrix is defined as:

Equation 2

$$D = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & dz & -dy & 1 & 0 & 0 \\ -dz & 0 & dx & 0 & 1 & 0 \\ dy & -dx & 0 & 0 & 0 & 1 \end{bmatrix}$$

Where “dx”, “dy”, and “dz” are the displacements along the x, y, and z axes respectively. The units of the displacements must match the distance components of the torque units used in your calibration (e.g., if your sensor reports torque in Newton-meters, the displacements must be measured in meters).

Because matrix math is associative, you can pre-calculate the factor from “Equation 1” and use the resulting matrix in all subsequent force/torque calculations, until you wish to create a new tool transformation.

It is important to note that the tool transformation procedure, as described here, applies the displacements and rotations in the following order:

1. Displacements. The order of axis displacements does not matter, as long as they are all done together with no rotations between displacements.
2. Rotation about X.
3. Rotation about Y.
4. Rotation about Z.

If you wish to apply the elements of the transform in a different order, you can either calculate the rotation and displacement matrices using the order appropriate to your application or you can apply the algorithm as described above multiple times, and only apply one element of the transform (e.g., one rotation or one displacement) at each step, as in the following pseudocode:

```
RegularTransform( x:matrix, y:transform ) : matrix
```

```
/* Procedure described above. */
```

```
RemoveFirstTransform( y:queue of transforms ) : transform
```

```
/* Removes first element from y and returns that element, or returns a null value if y is empty. */
```

```
OrderedTransform( x:matrix, y:queue of transforms ) : matrix
```

```
    z = RemoveFirstTransform( y )  
    if ( null = z )  
        return x  
    else  
        return OrderedTransform( RegularTransform( x, z ), y )
```

To use the above algorithm to apply transform elements in a particular order, you would construct a queue containing the transform elements in the order you wish to apply them, and then call the OrderedTransform method with the original calibration matrix and your transform list as arguments.

8.6 To Read Calibrated F/T Data from the Sensor

1. Set the sensor up to use the correct RS-485 baud rate for your application. By default, the sensor runs at 1,250,000 baud.
2. Optionally set the session ID register to protect against unexpected reboots.
3. Read the calibration information for the calibration you wish to activate, and apply any tool transformations you wish to apply to the calibration matrix to create the active calibration matrix.
4. Send the ‘Unlock storage command’ to unlock the active gain and offset hardware settings.
5. Write the active gain and offset hardware settings using the “GageGain” and “GageOffset” values from the calibration structure. You must do this every time the sensor is reset, because these values are not stored to nonvolatile memory.
6. Send the “unlock storage command” again to lock the gain and offset against accidental writing.
7. Send the “Start Streaming” command.
8. When each streaming sample is received, check the status bit for system health and the checksum for sample validity. If the status bit is 1, indicating a system error, go to step 11 to stop streaming, then read the system status word using standard Modbus.
9. To bias (tare) the sensor, take a reading when the sensor is in its default or unloaded state. Save these gage values as the “bias vector”. For each subsequent sample, subtract the bias vector from the sampled strain gage vector to remove the bias from the calculated F/T data.
10. Multiply the strain gage vector (with the bias vector subtracted) by the active calibration matrix to calculate the F/T values. The resulting vector will contain the force and torque values, scaled by the counts per force and counts per torque reported in the calibration structure.
11. When you are ready to stop streaming, send a jamming sequence of 14 bytes (one byte longer than the streaming sample size) to ensure the sensor receives at least one character. Wait before sending any more Modbus commands to allow the sensor’s internal Modbus stack to timeout and throw away the characters from the jamming sequence.

9. Terms and Conditions of Sale

The following Terms and Conditions are a supplement to and include a portion of ATI's Standard Terms and Conditions, which are on file at ATI and available upon request.

ATI warrants to Purchaser that force torque sensor products purchased hereunder will be free from defects in material and workmanship under normal use for a period of one year from the date of shipment. This warranty does not cover components subject to wear and tear under normal usage or those requiring periodic replacement. ATI will have no liability under this warranty unless: (a) ATI is given written notice of the claimed defect and a description thereof with thirty (30) days after Purchaser discovers the defect and in any event, not later than the last day of the warranty period and (b) the defective item is received by ATI not later than (10) days after the last day of the warranty period. ATI's entire liability and Purchaser's sole remedy under this warranty is limited to repair or replacement, at ATI's election, of the defective part or item or, at ATI's election, refund of the price paid for the item. The foregoing warranty does not apply to any defect or failure resulting from improper installation, operation, maintenance, or repair by anyone other than ATI.

ATI will in no event be liable for incidental, consequential, or special damages of any kind, even if ATI has been advised of the possibility of such damages. ATI's aggregate liability will in no event exceed the amount paid by the purchaser for the item which is the subject of claim or dispute. ATI will have no liability of any kind for failure of any equipment or other items not supplied by ATI.

No action against ATI, regardless of form, arising out of or in any way connected with products or services supplied hereunder, may be brought more than one year after the cause of action accrued.

No representation or agreement varying or extending the warranty and limitation of remedy provisions contained herein is authorized by ATI, and may not be relied upon as having been authorized by ATI, unless in writing and signed by an executive officer of ATI.

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Without ATI's prior written permission, Purchaser will not use such information for any other purpose or provide or otherwise make such information available to any third party. Purchaser agrees to take all reasonable precautions to prevent any unauthorized use or disclosure of such information.

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